EFFECTS OF VARYING SURFACE INCLINES AND SUIT PRESSURE; IMPLICATIONS ON SPACE SUIT DESIGN

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INTRODUCTION

Suited human performance studies in reduced gravity environments to date include limited observations from Apollo Lunar surface Extravehicular Activities (EVA) and from previous studies conducted in partial gravity simulation environments. The Constellation Program EVA Systems Project office has initiated tests to develop design requirements for the next generation Lunar EVA suit. Theses studies were conducted in the Space Vehicle Mock-Up Facility (SVMF) at Johnson Space Center from which the results provided recommendations for suit weight, mass, center of gravity, pressure, and suit kinematic constraints that optimize human performance in partial gravity environments.

METHODS AND PROCEDURES

All studies at the SVMF used a pneumatic cylinder servo controlled to a strain gauge to result in a constant simulated gravitational offloading throughout the subject's motion. All subjects donned the Mark III (MKIII) technology demonstrator suit. A gimbal support structure attached to the end of the lifting actuator supported a suited subject and allowed for the pitch, roll, and yaw rotational degrees-of-freedom during movement. Six astronauts approved by NASA JSC Committee for the Protection of Human Subjects walked at 10, 20, and 30 percent inclines on a VacuMed treadmill instrumented with four strain gauge force plates (1000 Hz, AMTI, Watertown, MA) that recorded the forces and moments under feet. Three-dimensional trajectories of 65 retro-reflective markers placed at approximate anatomical landmarks on the MKIII suit were digitized (100 Hz, Vicon, Oxford, UK) to determine the displacement of the segments of the suit. This information was used for subsequent analysis to describe the kinematics of the MKIII suit during treadmill ambulation at varying suit pressures. Each astronaut completed each ambulation trial for 30 gait cycles at 5 different suit pressures: 1.0, 3.0, 4.3, 5.0 and 6.5 psi. The suit weight was held constant at 1/6th the combined suit plus body weight for each astronaut.

RESULTS

Peak vertical ground reaction force (GRF) data were normalized to 1/6th each astronauts' body weight plus the 265lb MKIII suit (LSBW). This method was chosen since the specific aim of the study was to determine the effects of different suit pressures in lunar gravity rather than Earth gravity. There was little change in the magnitude of the average peak vertical GRF while walking up inclines

or with changing pressure (Table 1). Knee flexion at initial contact increased with an increase in incline (Figure 1). Varying suit pressures did not affect the knee joint angular displacement across the gait cycle. Cadence tended to increase as incline increased (Figure 2) but was not affected by pressure.

Table 1. Average peak vertical GRF normalized LSBW at varying pressures.

Incline	1.0	3.0	4.3	5.0	6.5
10	1.8	1.8	1.8	2.0	2.0
20	1.9	1.9	1.9	2.0	2.0
30	1.8	1.9	1.8	2.0	1.8

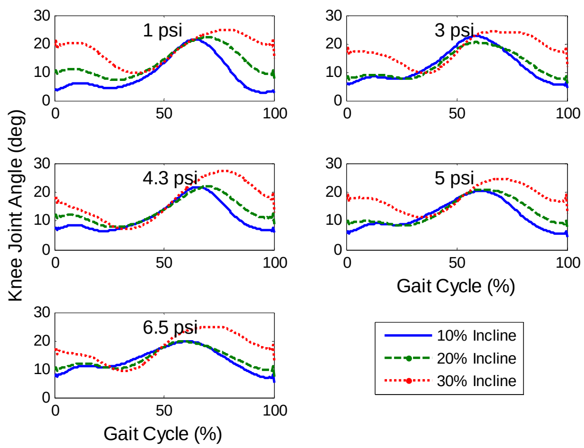

Figure 1. Average knee joint kinematics normalized against time and averaged between subjects.

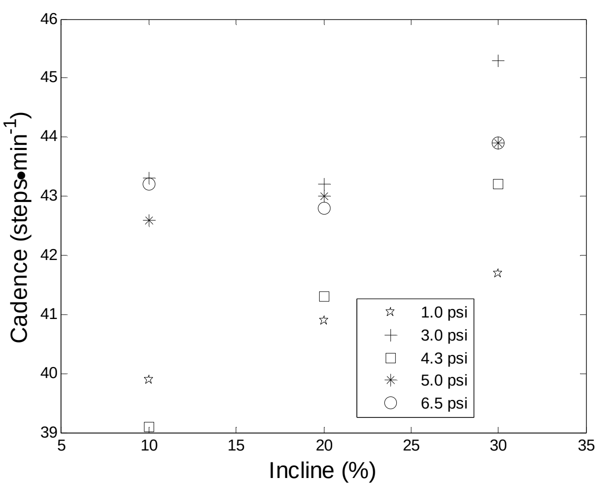

Figure 2. Cadence averaged between subjects.

DISCUSSION

The GRF data revealed minimal change across different varying inclines or across different suit pressures. The GRF analysis with this normalization scheme can be used to help quantify the amount of loading applied to the musculoskeletal system during EVA locomotion. This information can be further used to develop an exercise protocol to complement this loading as a result of an EVA. The increase in joint angle as incline increases can be attributed to raising and lowering of the body with uphill walking. A.S. McIntosh et al. (2006) reported decreases in cadence with increasing inclines in normal un-suited treadmill walking. They speculated that their findings may have been a result of a short walkway which did not allow for a steady gait pattern. One possible explanation for the differences in our findings is the subjects achieved steady gait after which 30 gait cycles were collected. Further the subjects were wearing a 265 lb space suit which was off-loaded to simulate lunar gravity. While in fact the subjects may have "weighed" less, the mass and inertia characteristics of the subject and suit remained unchanged. Hence, with increasing inclines they may have needed to take more frequent steps to compensate for the suit.

SUMMARY

This study showed walking on an incline while wearing the MKIII requires greater knee joint motion but there is no effect in varying the suit pressure. This is particularly important for design requirements for the next generation Lunar EVA suit.

REFERENCES

McIntosh, AS et al. (2006). *J Biomechanics*, 39: 2491-2502.